

Development and Evaluation of the Habitat Demonstration Unit Medical Operations Workstation and Opportunities for Future Research

Robert L. Howard, Jr., Ph.D.
Habitability and Human Factors Branch
NASA
Houston, TX, USA
robert.l.howard@nasa.gov

Abstract - As NASA develops missions to leave Earth orbit and explore distant destinations (Mars, Moon, Asteroids) it is necessary to rethink human spaceflight paradigms in the life sciences. Standards developed for low earth orbit human spaceflight may not be fully applicable and in-space research may be required to develop new standards. Preventative and emergency medical care may require new capabilities never before used in space. Due to spacecraft volume limitations, this work area may also be shared with various animal and plant life science research. This paper explores the prototype Medical Operations Workstation within the NASA Habitat Demonstration Unit and discusses some of the lessons learned from field analogue missions involving the workstation.

Keywords: Exploration, medical, health, crew, injury emergency, biology, animal, plant, science, preventative, emergency.

1 Introduction

The Habitat Demonstration Unit (HDU) is a prototype testbed for the evaluation of future deep space habitation. It was originally designed for lunar application, but is customizable for missions not only to the lunar surface, but also Mars, asteroids, and a variety of other microgravity environments. The HDU is designed to support human-in-the-loop testing and analogue missions with various internal architectural arrangements. The HDU is composed of a core laboratory module and can be augmented with additional modules including an airlock, hygiene module, and inflatable crew quarters.

All anticipated human spaceflight missions require some form of medical care or life sciences activity. For missions beyond Low Earth Orbit (LEO), the medical need is more severe because an emergency evacuation will require a longer period of time than those in LEO (where return to Earth can be achieved in as few as 45 minutes) and in some missions, medical mission aborts are not possible due to distance or other orbital mechanics constraints. Life sciences will also be of increased importance due to unknowns associated with biological

processes beyond the protection of the Van Allen radiation belts.

2 HDU Spacecraft Scenarios

All long duration human spaceflight has been conducted to date in Low Earth Orbit. Under the NASA Constellation program, considerable effort was generated to exploring the design of long duration missions to the Moon. NASA's Lunar Surface Systems Project created a number of lunar surface scenarios, selecting one for more extended habitation testing. Scenario 12.1 involved a lunar outpost composed of three pressurized modules, each five meters in diameter, supplemented by four Lunar Electric Rovers (now referred to as Space Exploration Vehicles). One of the pressurized modules was denoted the Pressurized Excursion Module (PEM) and it served as a core laboratory module, containing facilities for general maintenance, spacesuit maintenance, geology, and medical operations. The HDU was outfitted as the PEM for field testing during NASA analogue missions and human-in-the-loop testing from the summer of 2010 through early winter 2011.

The HDU was reconfigured following PEM testing to serve as part of the Deep Space Habitat (DSH), a more generic habitation system intended for a variety of missions beyond Low Earth Orbit. In the summer of 2011, the HDU was specifically outfitted as part of a DSH intended for a microgravity mission to an asteroid. Still a core laboratory module, the HDU-DSH contains facilities for general maintenance, teleoperations, geology, and medical operations. In addition to this lab module, two additional modules were added – a cylindrical module was docked to the side containing hygiene facilities and an inflatable loft manufactured via a student competition was docked to the top, providing an additional 1.5 decks devoted to crew quarters, galley, exercise, stowage, and office work. Human-in-the-loop testing of the HDU-DSH was conducted in the summer of 2011.

3 MOWS Construction

3.1 RPI Development

The MOWS was originally an unfunded aspect of the HDU project. This led to a student engagement venture that used an existing NASA collaboration with Rensselaer Polytechnic Institute (RPI) to build the initial version of the workstation. RPI's biomedical engineering and architecture departments collaborated as an undergraduate student project to design and build a medical facility to fit within the volumetric constraints defined by the HDU. Limited advice was provided by NASA space medicine personnel, but all of the design and construction was conducted by the students.

The unit delivered to Johnson Space Center for incorporation included a fixed medical desk, a repositionable surgical table, task lighting, and stowage drawers. A set of reconfigurable chairs that could morph into equipment tables were to have been included, but these failed during manufacture and were not shipped. Standard office chairs were used instead. Significant problems were encountered with the stowage drawers and these were replaced by Rhode Island School of Design interns, who designed a replacement stowage drawer system incorporating ten excess half-height Space Shuttle mid-deck locker drawers. This configuration was tested by the HDU-PEM.

When the HDU was refitted as the DSH, there were moderate changes made to the workstation. Due to the addition of a vertical lift in the center of the HDU, the surgical table no longer fit within the available volume. NASA contractors rebuilt the medical desk and surgical table, keeping the RPI table cover. (The cover provides a metal surface for patient treatment in cases where a hard, smooth surface is needed. Beneath the cover a mattress provides an insulated, padded surface for cases requiring electrical isolation or long term patient treatment.) The RPI table had a fixed anchor position near the center of the habitat and rotated about that point. By comparison, the rebuilt table is mounted on spring-loaded wheels and stows underneath the new medical desk. Additionally, the task lighting, which did not work well in 2010 testing, was replaced. Two additional full-height Space Shuttle mid-deck lockers were added as a rolling cart, stowed under the surgical table.

4 MOWS Mission

In both configurations of the HDU, its Medical Operations Workstation (MOWS) has served essentially the same four purposes: provide preventative medical care, provide emergency medical care, conduct human subject research, and conduct life sciences research.

4.1 Preventative Medical Care

Preventative medical care includes all of the basic medical examinations, doctor-patient consultations, laboratory analyses, and other medical activity to prevent disease or injury. As one exception, this does not include exercise, which is provided for elsewhere in both the PEM and DSH configurations of long duration space habitats.

The NASA Human Integration Design Handbook (HIDH) provides only limited guidance with respect to preventative medical care. It does specify that the medical area must support health monitoring, with the additional stipulation that this monitoring must be accomplished with little to no real-time support from Earth[1]. It also notes that access to patient medical history and medical procedures must be provided[1]. While not directly stated as requirements, it can be inferred that the medical station should allow for monitoring or access to monitored data related to air and water quality and other environmental conditions, routine physical examinations, and physiological monitoring during exercise.

4.2 Emergency Medical Care

Emergency medical care, by comparison, relates to response to medical emergencies. This may include both injuries and illnesses. In general, the MOWS is the sole resource for medical care for crew injuries. In the case of many injuries, a crew member may not be able to return to Earth in an injured state. Consequently, the MOWS must provide the full range of medical treatment to enable injured crew members to survive the remaining mission duration. The human spaceflight community has given perhaps the greatest level of attention to this particular mission of the MOWS. The space medicine community has defined five "levels of care" to apply to various classes of human spaceflight missions. Levels four and five are most directly applicable to the various missions proposed for the Deep Space Habitat.

Level of Care Four is intended for missions between 30-210 days in duration where return to Earth is not readily available, requiring on the order of days[2] (as opposed to minutes or hours for return from LEO). The risk of medical emergency is presumed to be moderate to high[2]. Triage is part of the medical strategy as the act of treating an injured crew member may consume resources (e.g. water, oxygen) or increase risk (e.g. fire risk) to the point of threatening the survival of the remaining crew members[2]. The crew is to be self-sufficient for immediate medical care, relying only on ground medical support in the consultation role[2]. The medical facility should support Space Motion Sickness, First Aid, Private Audio and video, Anaphylaxis Response, Clinical Diagnostics, Ambulatory Care, Private Telemedicine, Trauma Care, Medical Imaging, Sustainable Advanced Life Support, Dental care, and Limited Surgical care[3].

By comparison, Level of Care Five denotes missions in excess of 210 days and return to Earth is not considered a viable option[2]. This reflects the notion of a mission to destinations further from home than in Level of Care Four and therefore an increased capability required. The risk of medical emergency is presumed to be high and the caregiver is to have training at the physician level[2]. The medical facility should support space motion sickness, first aid, private audio and video, anaphylaxis response, clinical diagnostics, private telemedicine, trauma care, medical imaging, dental care, autonomous advanced life support and ambulatory care, and basic surgical care[3].

4.3 Human Subject Research

Human subject research encompasses biomedical assessments intended to better understand the response of the human body to the space environment. This may include both microgravity research (as in the case of the DSH asteroid mission) or low gravity research (as in the case of the lunar PEM or a Mars surface mission). It is also of strong interest to understand the effects of Galactic Cosmic Radiation experienced on deep space missions outside of Earth's Van Allen Radiation Belts. American and Russian space stations and spacecraft have historically conducted extensive human subject research to better understand human health complications from microgravity, radiation, and other space environmental factors and to test the effectiveness of countermeasures.

4.4 Life Science Research

Life science research encompasses biological and biochemical research not involving human test subjects. This may include animal, insect, or plant research, or even cellular or molecular chemistry. Often, this fundamental research is a prerequisite to understanding the impacts of spaceflight or more complicated forms of life, such as humans. It may also enable other space technologies, such as in-flight food production, biological oxygen and water recycling, and radiation protection.

5 MOWS Performance

The MOWS has been tested during two NASA analogue missions and one human-in-the-loop test. A number of human factors techniques were used to evaluate the usability and volumetric adequacy of the workstation.

5.1 2010 Desert RATS

During the summer of 2010, the MOWS was tested during the NASA Desert Research and Technology Studies (Desert RATS) analogue mission at Black Point Lava Flow, Arizona. In this test, four emergency medicine procedures were tested: cardiac arrest, cranial bump, laceration repair, and forearm break. Preventative medical care, human subject research, and life sciences research were not tested at the 2010 Desert RATS.

Crews considered the overall design and layout of the MOWS as borderline[4]. They also reported that the station did not provide sufficient privacy and lacked sufficient work space to effectively aid patients while on the medical table[4]. The MOWS did not contain a privacy curtain in the PEM configuration and crews suggested adding a deployable curtain. A need for more flat surface space to stage supplies when treating a patient was also identified[4].



Figure 1. Crew member undergoing laceration repair

As shown in figures 2 and 3, conflicts may occur with respect to the positioning of the patient and the medical supplies stowage. The medical table is supposed to be rotated 90 degrees prior to initiating treatment. However, most test subjects were observed to forget to rotate the table at some point. This resulted in the patient's head being directly underneath the medical stowage and this created a risk of dropping medical equipment on the head of the patient.

It should be noted that when test subjects did remember to rotate the surgical table there was some interference with the Geology workstation[4]. However, this was considered to be generally acceptable as the table would primarily be rotated for specific activities. Generally, and preventative medical care or human research could be scheduled to not coincide with geology activity. It is expected that in the event of a medical emergency, geology operations would be suspended to free up the associated crew member(s) to assist.

It is also worth noting that different test subjects chose to interact with their patients in different ways. For instance, in figure 1, the patient is seated on the surgical table with the caregiver standing in front of the patient while treating a laceration. When the workstation was initially designed, this specific procedure was intended to be executed with the patient seated on one side of the table and the caregiver on the other, with the injured arm resting on the table between them. Some test subjects chose the

seated position (as shown in figure 4) while others chose to treat patients while standing.



Figure 2. Medical supplies over head of patient when table not properly rotated



Figure 3. Medical supplies no longer over head of patient when table properly rotated

5.2 Incapacitated Crew Member Evaluation

The MOWS was also tested as part of a winter 2011 human-in-the-loop evaluation of incapacitated EVA (extra-vehicular activity) crew member treatment. The MOWS component of this test involved a simulated decompression sickness treatment. It should be noted that this test did not involve a full four-person crew and did not involve concurrent activities at other workstations. That being said, test subjects had generally positive comments about the workstation.

One test subject in particular commented, “The size and space to maneuver around the medical operations station went well[5].” Test subjects particularly noted that they felt comfortable providing care for the injured crew

member from any location around the workstation[5], demonstrating satisfaction of a key design requirement. Because a crew member could potentially receive an injury to any part of the body, space medicine doctors had requested that the workstation provide the care giver with 360 degree access to the patient’s body.



Figure 4. Test subject administering aid to mock-up incapacitated crew member

Test subjects requested that wheels be added to the surgical table (with locks to prevent inadvertent movement) to make deployment easier[5] as shown in figure 5. They also suggested that the surgical table should be adjustable and that restraints be provided for both the caregiver and patient, particularly when giving chest compressions[5]. Even in the low gravity of the Moon or Mars they felt such restraints would be necessary. They also suggested hinging the cover to the surgical table or providing a dedicated space in the HDU to stow the removable table cover[5].

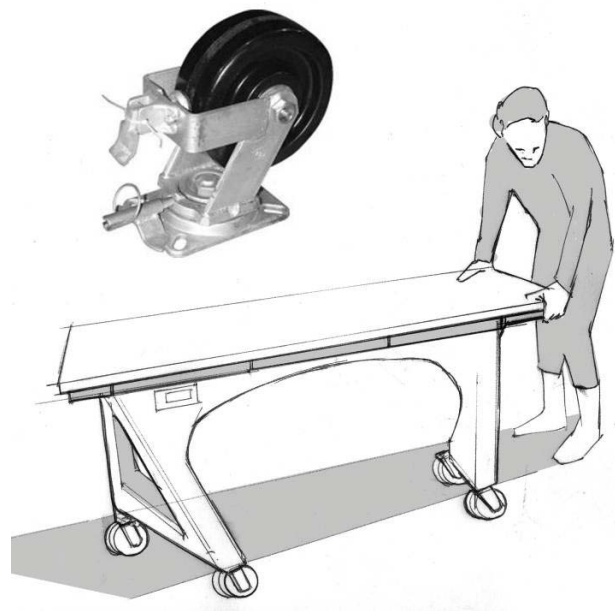


Figure 5. Surgical Table with Lockable Wheels

An issue raised but not adequately tested involves the translation of an injured crew member from the point of injury to the surgical table. This evaluation simulated an incapacitated crew member having been brought in from a spacewalk on the lunar surface. Material handling aids are available on the lunar surface and in the airlock to position the crew member at the entrance to the module interior. The caregiver then physically carried a mannequin (simulating the injured crew member) from the airlock hatch to the surgical table, as shown in figure 6. While lunar gravity is sufficiently low that this is likely a trivial task, more analysis is needed to see if any aids are necessary for a similar act at a Mars outpost.



Figure 6. Injured Crew Member Carried to Surgical Table

Test subjects also noted difficulty accessing the storage drawers and suggested enabling them to tilt down as shown in figure 7. Note that the female test subject is standing on her toes in order to see what is in one of the lower storage drawers.

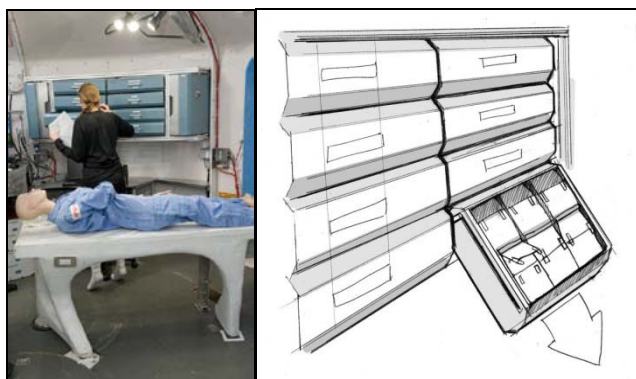


Figure 7. Need for Tilt Down Stowage Drawers

Other suggestions included: making the medical waste stowage more accessible, adding additional deployable surfaces around the surgical table (especially a sterilized surface for holding medical supplies and instruments), increasing the surface area on the fixed desk, adding built-in drawers beneath the surgical table surface,

increased lighting, and a drop down computer display and remote computer for patient monitoring.

5.3 2011 Desert RATS

In the summer of 2011, the MOWS was tested again at NASA Desert RATS. Figure 8 shows the MOWS configuration used to reflect the Deep Space Habitat redesign. Compare this view with figure 1 to best visualize the change in configuration.

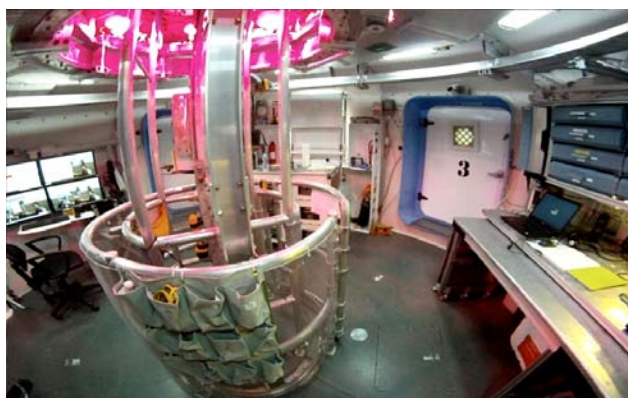


Figure 8. DSH MOWS Configuration

Both the fixed medical desk and deployable surgical table were replaced for the 2011 field trials. The new deployable table slides underneath the fixed table when stowed and can be positioned essentially anywhere there is room in the Lab when deployed. Figure 8 shows the new surgical table stowed under the fixed medical desk and figure 9 shows it in a partially deployed configuration.



Figure 9. MOWS Surgical Table partially deployed

Emergency medicine procedures tested were: eye examination, cardiac arrest, cranial bump, laceration repair, forearm break, and sprains and strains. Life science procedures tested were: biology glovebox deploy/stow (with sample inspection), and microscope sample analysis. Preventative medical care and human research were not tested at the 2011 Desert RATS.

In this evaluation, the MOWS was rated as overall acceptable for all tasks conducted[6]. However, crews reported space conflicts between the deployable table and both the airlock hatch and lift gate[6]. The configuration most often preferred by test subjects placed the surgical table against the lift, leaving a narrow volume for the care giver to work between the patient and the medical stowage. However, this did fully block use of the lift by preventing opening of the lift gate.

Also, when seated at the medical desk, test subjects noticed that it was easy to strike a knee under the desk or against the rolling stowage cart. Largely due to these concerns, crews suggested replacing the medical chair with a stool that requires less volume for use[6].

The 2011 field trials also increased the scope of work tested in the workstation as previously noted by incorporating life sciences testing. A deployable glove box was added to the workstation, which was reported as easy to both deploy and stow[6]. Areas considered borderline in the workstation were privacy, off-nominal situations, and access/reach to equipment[6]. Privacy continued to be an issue despite improvements from 2010. The 2011 configuration features deployable privacy curtains, but these curtains provide only visual privacy. It is desired to also provide some sound suppression with these curtains. Also, the curtains do not fully enclose the patient and caregiver in some treatment conditions. While not measured in the field trials, it is clear that a deep space mission in microgravity would require means to contain fluids. This may include both suction in various components and design of the curtains to prevent spills from migrating to other regions of the spacecraft.

Additionally, though time was not measured in this evaluation, it was noted that it took a significant amount of time to set up the privacy curtains and configure the medical workstation to treat a patient. Test subjects noted that in a medical emergency they simply would not bother with this set up, indicating that some redesign of the privacy system is needed to enable rapid deployment.

Some issues were also reported with the medical stowage. Space Shuttle mid-deck lockers and drawers were used for all of the MOWS stowage, as shown in Figure 10. However, there was no internal organization within the drawers, thereby causing test subjects to have to rummage through the drawers for every item called out by medical or science procedures. Crews suggested at minimum consolidating items based on whether their use is for emergency treatment, basic treatment, or science research[6].



Figure 10. MOWS overhead stowage drawers and cabinets

6 Future Research Opportunities

6.1 Life Science Exploration Strategy

The medical community has developed levels of necessary care for different types of space mission, including many of the types of long duration missions encountered by a Deep Space Habitat crew. However, similar levels of engagement have not been conducted by the non-human life science community. Both the space shuttle and space station have conducted numerous biological experiments involving plants, animals, insects, and cellular/biochemistry domains. There is no reason to believe that there will not be continued needs for such fundamental research in space missions beyond Low Earth Orbit. These activities will have stowage and task volume implications for the Medical Operations Workstation and the workstation cannot be fully defined without greater definition of these potential science mission objectives.

6.2 Manpower Assessment

It is also important to determine if these are single-person or multiple-person tasks. As an example the HDU Geology Workstation has often struggled with manning because it is difficult for a single person to access computer data systems while using the geology glovebox, which dominates geology activities. Using two crew members enables faster task completion, but is often a poor use of the second crew member's time, generally using this person only to type for the crew member using the glovebox. Using a single crew member causes tasks to take longer and is often annoying for the crew member, who is frequently having to remove hands from the glovebox to access the crew member. A yet to be tried third approach involves using robotic manipulators in the glovebox, thus avoiding the need for the crewmember to place hands in the glovebox at all. Similar task evaluations will need to be conducted for life science tasks, which may or may not involve use of a biology glovebox. Other issues that may drive the number of caregivers include maintaining sterility and access to stowed medical supplies during patient treatment.

6.3 Technology Development

There are also numerous opportunities for technology development in three key areas: research hardware and software, medical hardware and software, and integrated system testing. As noted previously, the workstation has not been outfitted with high fidelity medical hardware. It is awaiting opportunity to evaluate many of the medical systems currently under development and ensure that those systems are indeed compatible with the volumes being allocated under Deep Space Habitat concepts being considered.

6.4 Test Metrics

As the workstation is updated and incorporated into system testing, several metrics will help to refine the workstation design. Data should be collected related to crew efficiency/accuracy, workstation usability, crew member fatigue and discomfort (caregiver, researcher, and patient/test subject), manpower, required operator skill, and interference with other workstations (volumetric, auditory, and other). Tests will need to include both nominal and off-nominal activities. Because the Medical Operations Workstation is used for multiple functions, it is especially important to test off-nominal conditions where a medical emergency occurs while the station is already deployed for a complex life sciences research task.

7 Conclusions

Significant information has been gleaned from the HDU Medical Operations Workstation over the course of three human-in-the-loop evaluations that has helped to inform the requirements for medical care on exploration class mission. While the entire range of potential activities has not yet been tested in the MOWS, preliminary data collected in early tests has scoped what level of medical capability is possible within a Deep Space Habitat class vehicle for exploration missions. The need for a dedicated medical facility (though shared with other functions) is clearly established and some understanding of the volumes and work surfaces has been achieved. It is further possible to begin to estimate the power and data connectivity requirements, based on equipment used or recommended for use in the MOWS to date.

Acknowledgment

Special thanks are extended to the 2010 and 2011 Desert RATS crew members and support teams, participants in the HDU Airlock Operations and Incapacitated Crew Member evaluation, members of the Habitat Demonstration Unit team, Rick Scheuring and Victor Hurst of the NASA JSC space medicine Division, and participating students from RPI and RISD.

References

- [1] *Human Integration Design Handbook*, pp. 514-516, NASA, Washington, DC, January 2010.
- [2] *NASA Space Flight Human System Standard Volume 1: Crew Health*, NASA-STD-3001, Volume 1, pp. 15,16, 44, 45, NASA, Washington, DC, March, 2007.
- [3] *NASA Space Flight Human System Standard Volume 2: Human Factors, Habitability, and Environmental Health*, NASA-STD-3001, Volume 2, pp. 83, NASA, Washington, DC, January 2011.
- [4] Harry L. Litaker, Jr., Ronald D. Archer, Robert L. Howard, Jr., Ph.D., Richard Szabo, Evan S. Twyford, Carl S. Conlee, "A Human Factors Assessment of the Habitat Demonstration Unit (HDU) During a 14-Day Desert Field Trial", NASA Johnson Space Center, November 2010.
- [5] Harry L. Litaker, Jr., Richard Szabo, Robert L. Howard, Jr., Ph.D., Evan S. Twyford, Carl S. Conlee, Steve P. Chappell, Ph.D., Kathryn C. Mitchell, HDU Airlock Operations and Incapacitated Crew Member Final Report, NASA Johnson Space Center, February 2011.
- [6] Harry L. Litaker, Jr., Shelby G. Thompson, Ph.D., Ronald D. Archer, Richard Szabo, Robert L. Howard, Jr., Ph.D., A Human Factors Evaluation of the Deep Space Habitat (DSH) Architectural Configuration, NASA Johnson Space Center, November 2011.